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INVESTIGATION OF REMOTE SENSING TO DETECT NEAR-SURFACE GROUNDWATER ON IRRIGATED LANDS

by

Dennis W. Ryland, Fred A. Schmer, and Donald G. Moore

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INVESTIGATION OF REMOTE SENSING TO DETECT NEAR-SURFACE GROUNDWATER ON IRRIGATED LANDS

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ABSTRACT

This research was a continuation of the study started in mid-1972 to investigate the application of remote sensing techniques for detecting areas with high water tables in irrigated agricultural lands. Aerial data were collected by the LANDSAT-1 satellite and aircraft over the Kansas/Bostwick Irrigation District in Republic and Jewell Counties, Kansas. LANDSAT-1 data for May 12 and August 10, 1973, and aircraft flights (midday and predawn) on August 10 and 11, 1973, and June 25 and 26, 1974, were obtained. Surface and water table contour maps and active observation well hydrographs were obtained from the Bureau of Reclamation for use in the analysis.

Data analysis consisted of the application of the statistical methods of linear correlation, multiple correlation and regression, mode seeking, and K-class classification to digital values obtained with the Signal Analysis Dissemination Equipment (SADE). Water table depths were obtained from the surface and water table elevation contour maps and the observation well hydrographs provided by the Bureau of Reclamation.

Results of the study revealed that LANDSAT-1 data (May MSS band 6 and August MSS band 7) did correlate significantly (0.01 level) with water table depth for 144 active observation wells located throughout the Kansas/Bostwick Irrigation District. However, a map of water table depths of less than 1.83 meters prepared from the LANDSAT-1 data did not compare favorably with a map of seeped lands of less than 1.22 m (4 feet) to the water table. Field evaluation of the map is necessary for a complete analysis.

Analysis of three fields on a within or single-field basis for the 1973 LANDSAT-1 data also showed significant correlation results. Correlation of aircraft data with water table depth for five fields

using 1973 and 1974 data showed significant results for several film-filter combinations. Results from the mode seeking algorithm indicated the potential of LANDSAT-1 data for the preparation of maps relating to water table depth. Using mode seeking to train the K-class classifier, 76 percent of the water table depths for a corn field were correctly classified into depths of less than 183 cm (6 feet) and depths greater than 183 cm.

Keywords - remote sensing, hydrographs, water table depths, seeped lands, irrigation, contour maps, aerial data.

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INTRODUCTION

This research was a continuation of the study started in mid-1972 to evaluate remote sensing capabilities for improving the efficiency of identifying internal drainage problem areas. The study area, shown in Figure 1, was expanded to include the entire Kansas/Bostwick Irrigation District located in Republic and Jewell Counties in North-central Kansas.

The specific objectives were:

1) Continue to investigate the reliability of remotely sensed (LANDSAT-1 and aircraft data) land-surface indicators of water-table depths.
2) To map, to the extent possible, high water table regions in the proposed study area.

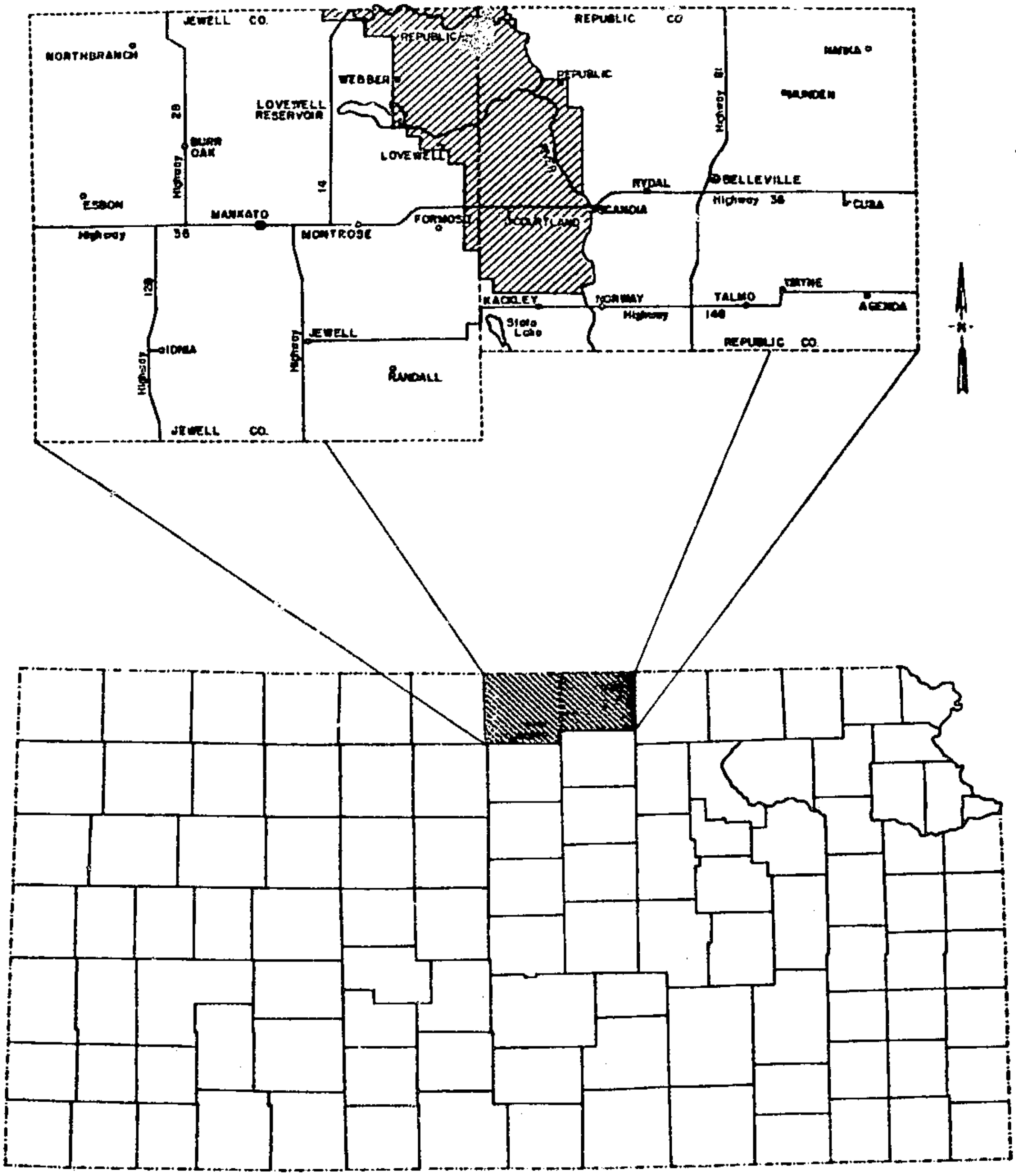

Figure 1. Location of the Kansas/Bostwick Irrigation District in Republic and Jewell Counties, Kansas.

PROCEDURES AND DATA COLLECTION

Ground-Truth Data Collection

Ground-truth data was provided primarily by Bureau of Reclamation personnel. Surface and water table elevation contour maps were also provided for specific areas selected for study. To aid in the selection of specific fields for analysis, on-site evaluations by RSI and Bureau personnel were conducted. Fields were selected on the basis of surface slope, surface conditions, type of crop, and the availability of the water table contour maps.

In order to use the existing water table contour maps, test wells were placed at various locations in each field. Probes were placed in areas where the water table was 1.52m (five feet) or less and allowed to stabilize for at least one day before being read. The location and depth to water for each test well was plotted on the existing contour maps and an estimate of the change in the water table depth for each field was determined. In addition to the updated contour maps, active observation well hydrographs in the irrigation district were also provided by the Bureau of Reclamation.

Aerial Data Collection

Aerial data used for analysis consisted of Remote Sensing Institute (RSI) aircraft data and LANDSAT-1 (formerly Earth Resources Technological Satellite-1) data. The RSI aerial data collection was accomplished with a twin engine Beechcraft, RC45J. One day and one night flight were conducted on August 10 and 11, 1973, at 1524m (5,000 ft) above ground level (AGL) and June 25 and 26, 1974, at 1524m AGL and 3048m (10,000 ft) AGL over selected areas of the Kansas/Bostwick Irrigation District. The June 1974 flights were planned for the spring, but were delayed due to unfavorable weather conditions.

LANDSAT-1, 9" x 9" positive transparencies for multispectral scanner bands 4, 5, 6, and 7 were obtained for May 12, 1973, and August 10, 1973. No LANDSAT-1 data were obtained for 1974. Table I lists the sensors, spectral ranges, and film types used for both the aircraft and LANDSAT-1.

TABLE I. TYPES OF AERIAL DATA COLLECTED BY LANDSAT AND AIRCRAFT PLATFORMS.

Variables	Spectral Range	Method of Collection
<u>Aircraft</u>		
Photography		
Color Film		70 mm Hasselblads
Color Infrared-15G/30M	$0.51 \rightarrow 0.90\ \mu m$	2443 Film
Color Film-HF3	$0.39 \rightarrow 0.70\ \mu m$	2448 Film
Black and White Film		
Red-25	$0.59 \rightarrow 0.70\ \mu m$	2402 Film
Near Infrared-89B	$0.68 \rightarrow 0.90\ \mu m$	2424 Film
Thermal Infrared	$8.70 \rightarrow 11.50\ \mu m$	Daedalus Line Scanner
<u>LANDSAT</u>		
Scanner Imagery		
Black and White Film		
Green-MSS 4	$0.5 \rightarrow 0.6\ \mu m$	Multispectral Scanner
Red-MSS 5	$0.6 \rightarrow 0.7\ \mu m$	
Infrared-MSS 6	$0.7 \rightarrow 0.8\ \mu m$	
Infrared-MSS 7	$0.8 \rightarrow 1.1\ \mu m$	

ANALYSES AND RESULTS

Analyses of the remote sensing data included the statistical methods of linear correlation, multiple correlation and regression, mode seeking, and K-class classification. The analyses techniques were applied to the entire Kansas/Bostwick Irrigation District and to specific fields selected for detailed analysis. The IBM 360 computer and Signal Analysis Dissemination Equipment (SADE) were used for the analysis.

Total Area Analysis

LANDSAT-1, 9" x 9" positive transparency data of the entire Kansas/ Bostwick Irrigation District were obtained for May 12 and August 10, 1973. The multispectral scanner (MSS) bands 4, 5, 6, and 7 were digitized with SADE at a resolution of approximately 36 data points per millimeter of transparency. This corresponds to ground coverage of 2452 square meters per data point. The transparencies for both dates were registered at the time of digitization. Computer printouts of portions of each MSS band were used to check the registration and make any adjustments necessary to insure the correct location of fields and observation well sites.

One hundred and fourty-four active observation wells located in areas with corn as the cover crop were selected from hydrographs provided by the Bureau of Reclamation. To aid in the selection of well sites in areas with corn as the cover crop, visual interpretation of the LANDSAT-1 transparencies and the computer printout of the August MSS band 5 was used. Figure 2 is a print of the August MSS band 5 showing the entire irrigation district with the section lines at one mile intervals and observation wells denoted. In general, the light areas denote vegetation such as corn and the dark areas denote fallow land. The range of digital values obtained from SADE for fields known to be corn was determined and only observation wells located in areas with this range were selected. The same well sites were used for the May 12 data when the ground cover was either fallow or crop residue from the previous growing season. However, it is likely that the fields had been prepared for the planting of corn by May 12 and were therefore fallow.

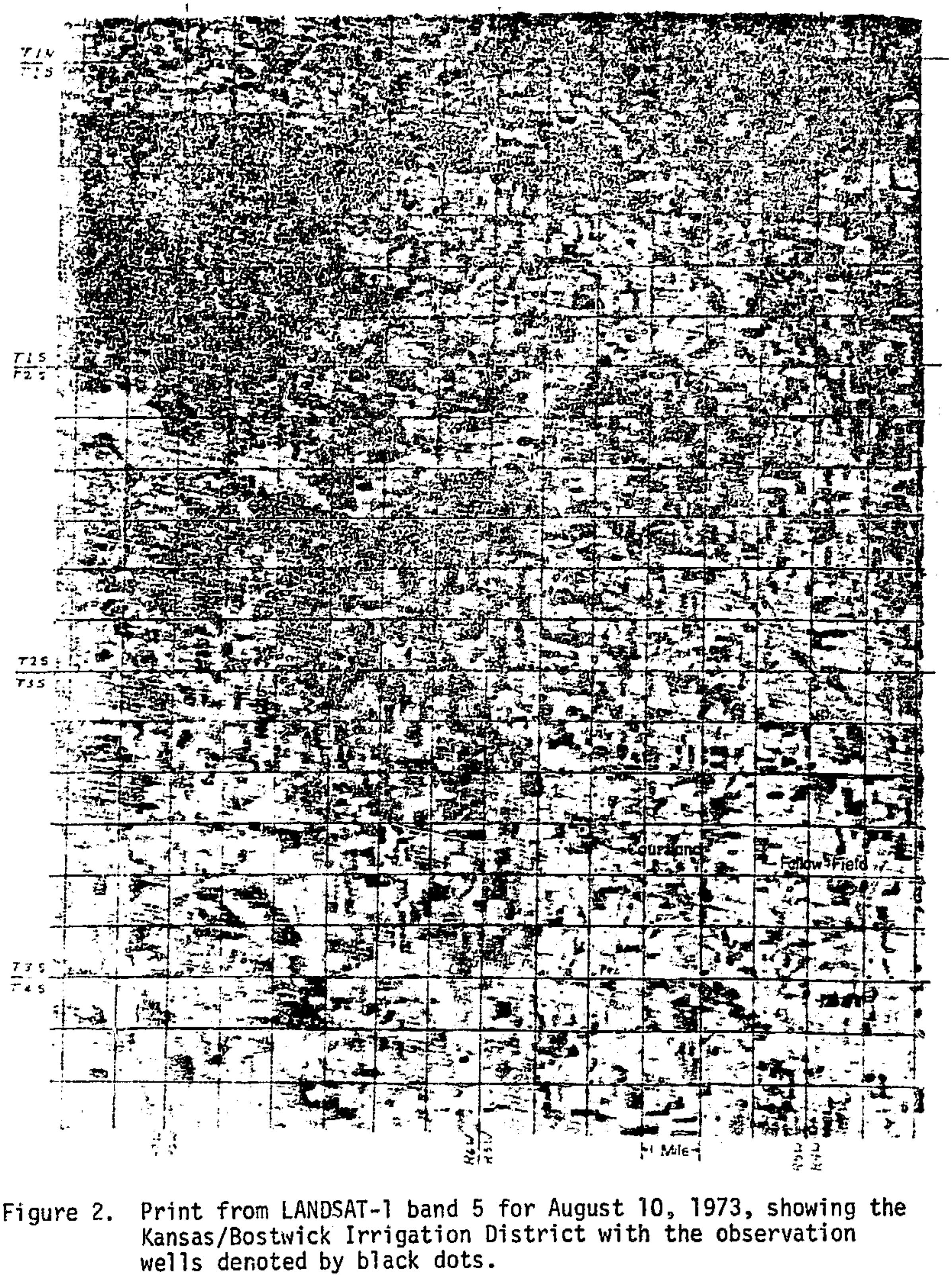

Figure 2. Print from LANDSAT-1 band 5 for August 10, 1973, showing the Kansas/Bostwick Irrigation District with the observation wells denoted by black dots.

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The average of a 2x2-digit matrix was obtained for each well site for each MSS band for correlation with the water table depth for each observation well. The results of the linear correlation of the average digital SADE values with the water table depth for each of the 144 observation wells is presented in Table II. The ground surface elevation, May water table elevation, and August water table elevation are also included. Significant correlations at the one percent level were obtained for all variables versus the May MSS band 6. The MSS band 5 for May also correlated significantly (0.01 level) with the May water table depth.

For the August data, MSS band 7 correlated significantly (0.01 level) with the August water table depth. It should be noted that the observation wells were located in various fields having different tillage practices, corn varieties, row direction, planting date, irrigation scheduling, etc., which add variance to the analysis that has no relationship to water table depths. This variance is reduced when analyzing a single field in contrast to a large area. However, the significant correlations for the total area do provide promise for use of LANDSAT data.

One objective was to develop a map of high water table areas in the Kansas/Bostwick Irrigation District. From the correlation results in Table II, the May MSS band 6 and the August MSS band 7 were selected for use in preparation of a water table map for the area shown in Figure 2. The range of digital SADE values for areas of corn was determined from computer printouts of the August MSS band 7. The same data point locations determined to be corn from the August MSS band 7 were used for the May MSS band 6, when the ground surface condition was probably fallow. The digital SADE values were substituted into the respective regression equations for the May MSS band 6 and the August MSS band 7. The regression equations for each date were:

$$WTD = 0.306\ (MSS\ 6) - 3.011 \qquad \text{(for May data)}$$
$$WTD = 0.162\ (MSS\ 7) - 12.746 \qquad \text{(for August data)}$$

where WTD is the predicted water table depth in feet. Figures 3 and 4 show the estimated regression line for the May and August regression

TABLE II. CORRELATION COEFFICIENTS FOR DIGITIZED MAY AND AUGUST, 1973, LANDSAT-1 IMAGERY VERSUS WATER TABLE DEPTHS AND ELEVATIONS FOR 144 OBSERVATION WELLS.

Variables	May LANDSAT-1				August LANDSAT-1			
	MSS-4	MSS-5	MSS-6	MSS-7	MSS-4	MSS-5	MSS-6	MSS-7
May Water Table Depth	0.151	0.217**	0.234**	0.159	0.003	-0.080	0.171*	0.311**
August Water Table Depth	0.129	0.194*	0.234**	0.161	-0.040	-0.105	0.162	0.303**
Ground Surface Elevation	0.133	0.160	0.269**	0.192*	0.147	0.000	0.103	0.135
May Water Table Elevation	0.106	0.117	0.236**	0.171*	0.166*	0.023	0.064	0.056
August Water Table Elevation	0.113	0.125	0.234**	0.171*	0.175*	0.029	0.067	0.062

** Significantly different from zero at the one percent level.
* Significantly different from zero at the five percent level.

142 Degrees of Freedom

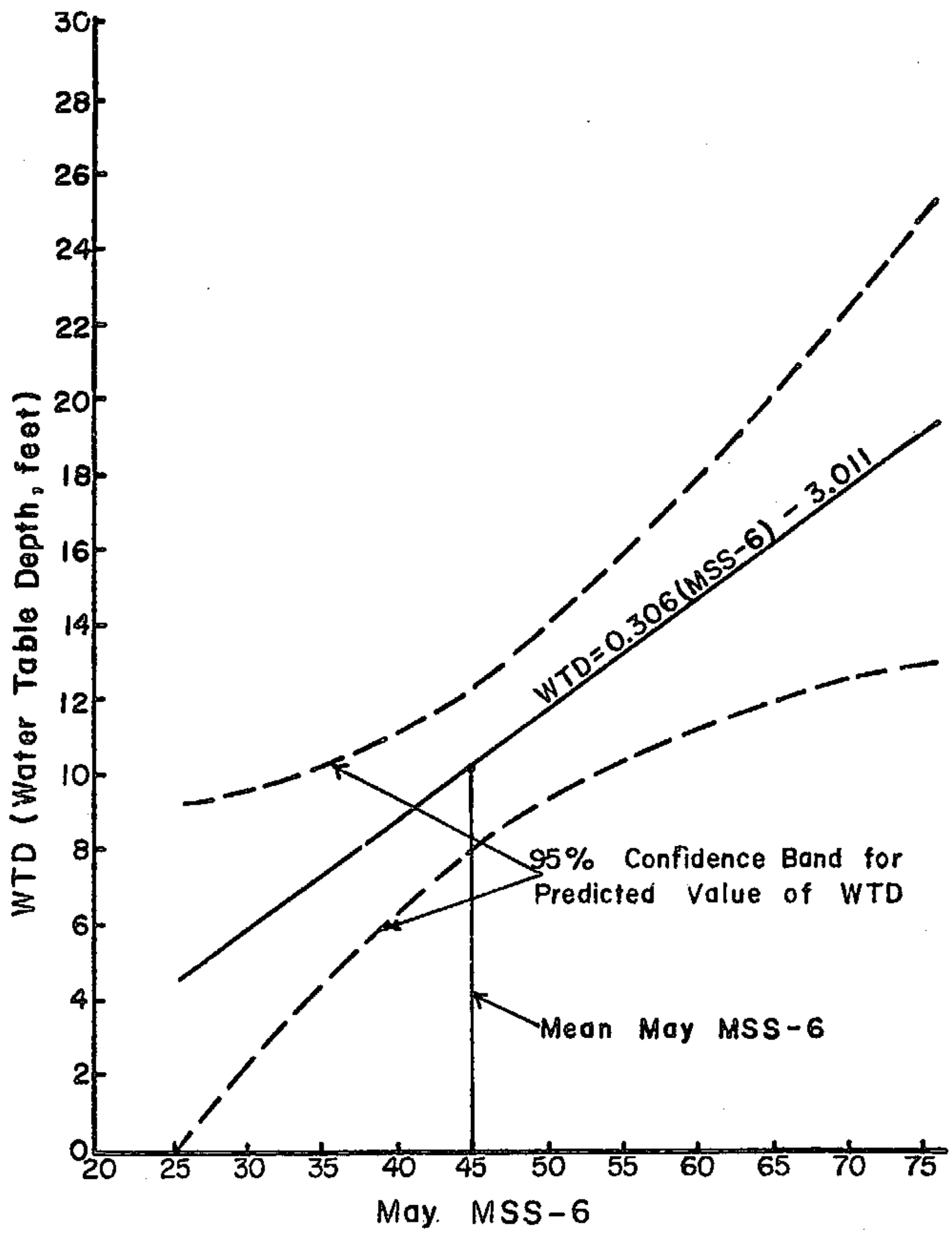

Figure 3. Estimated regression line (solid) for May LANDSAT MSS band 6 versus predicted water table depth. The dashed lines enclose the 95% confidence band for the predicted value of WTD.

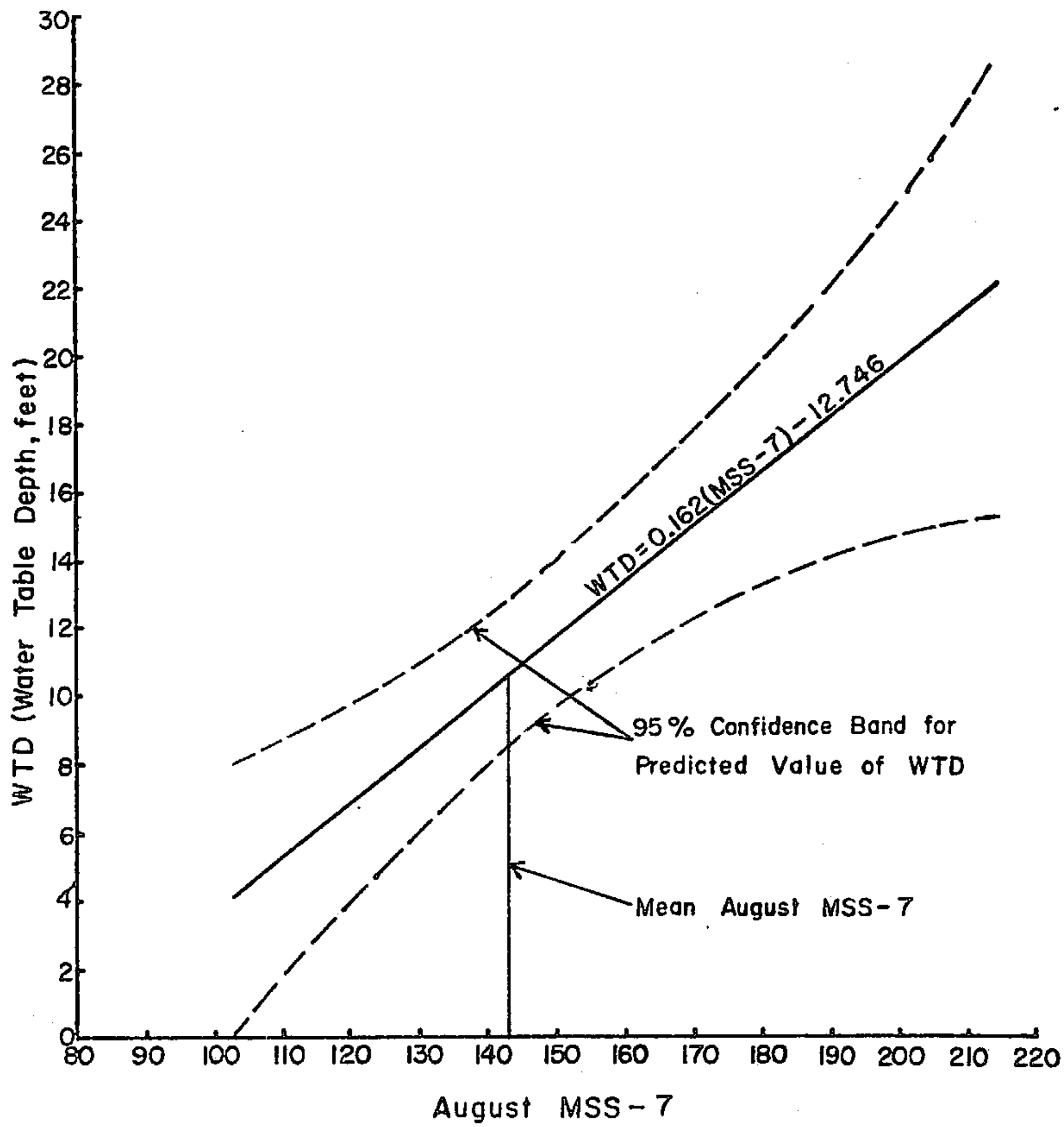

Figure 4. Estimated regression line (solid) for August LANDSAT MSS band 7 versus predicted water table depth, WTD. The dashed lines enclose the 95% confidence band for the predicted value of WTD.

equations, respectively. The 95 percent confidence band for the predicted value of WTD is shown by the dashed lines for each equation. A 95 percent confidence band of ±2.0 feet was obtained for both equations at the mean of MSS 6 and MSS 7, respectively.

A computer symbol map of the area was obtained from the regression equation for each date, with water tables of less than six feet (1.83 meters) and greater than six feet delineated. Data points not in the digital range of corn as determined from the August MSS band 7 were classified according to the next data point in the range of corn, either less than or greater than six feet (1.83 meters). To evaluate the computer symbol map, an overlay of water tables less than six feet (1.83 meters) was prepared on a map of seeped lands in the Kansas/ Bostwick Irrigation District. A print of the map and overlay from August MSS band 7 is shown in Figure 5. Visual comparison between the USBR seeped land map and the LANDSAT-1 overlay are not encouraging. However, the map should be field evaluated to provide an indication as to whether it is feasible to attempt to refine the technique. An overlay from the May MSS band 6 was not prepared because the results were even less encouraging than from the August MSS band 7.

Within-Field Analysis

Five fields were selected for analysis on a single field or within-field basis utilizing the methods of linear correlation, multiple correlation and regression, mode seeking, and K-class classification. Figure 6, 7, 8, 9, and 10 are prints of each field from black and white film exposed with a red filter taken on August 10, 1973, and June 25, 1974. Both the LANDSAT-1 data for May and August 1973 and aircraft data for August 10, 1973 were used for areas 3-5-11a, 3-5-26a, and 3-5-23d. Only the aircraft data for June 25 and 26, 1974, were used for areas 3-5-23d at two altitudes (1524m and 3048m AGL) and 2-5-23 at 3048m AGL. A print of area 3-5-23d at 1524m AGL was not included.

The SADE system was used to digitize the transparencies for the two LANDSAT-1 dates (May and August, 1973) and the aircraft data. The black and white films were digitized without a filter (neutral-N) and the color films were digitized without a filter (neutral-N) and with a red (R),

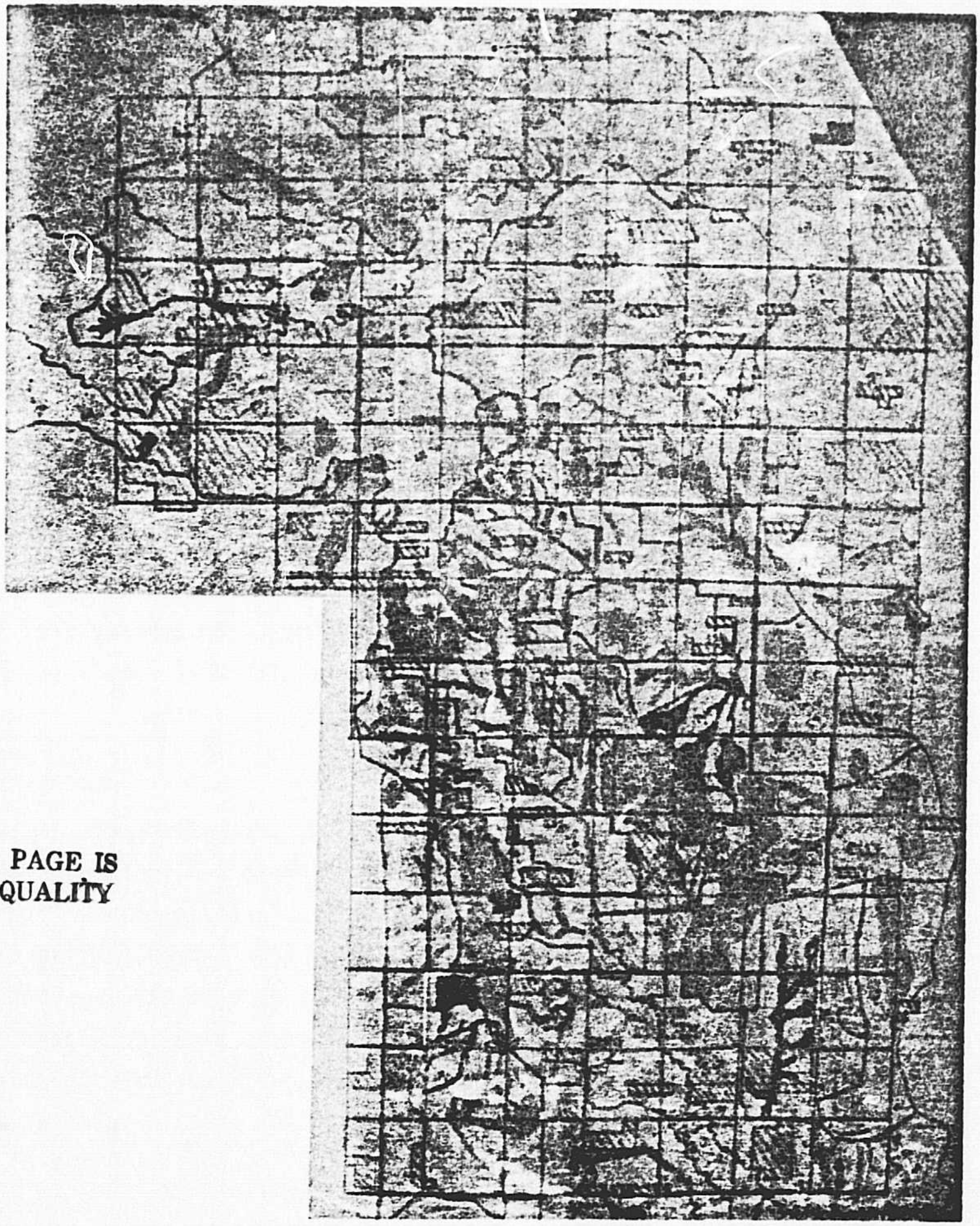

Figure 5. Print of USBR seeped land map (colored areas represent 4 ft or less to ground water) with overlay of water tables of less than 1.83m(6 ft) as determined from August LANDSAT-1 MSS band 7 (cross hatched areas).

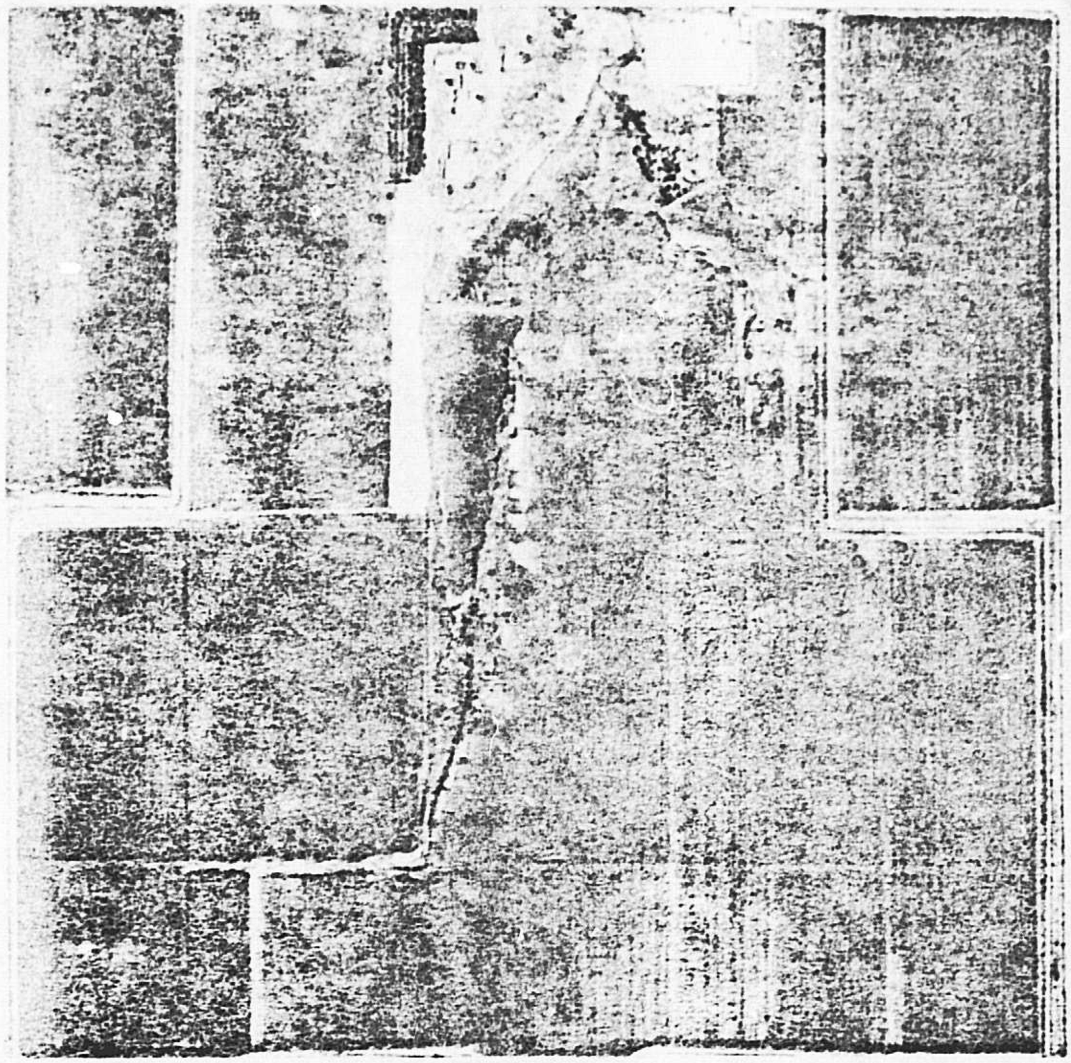

Figure 6. Print of area 3-5-11a at 1524 m agl from black and white film exposed with a red (25) filter taken on August 10, 1973.

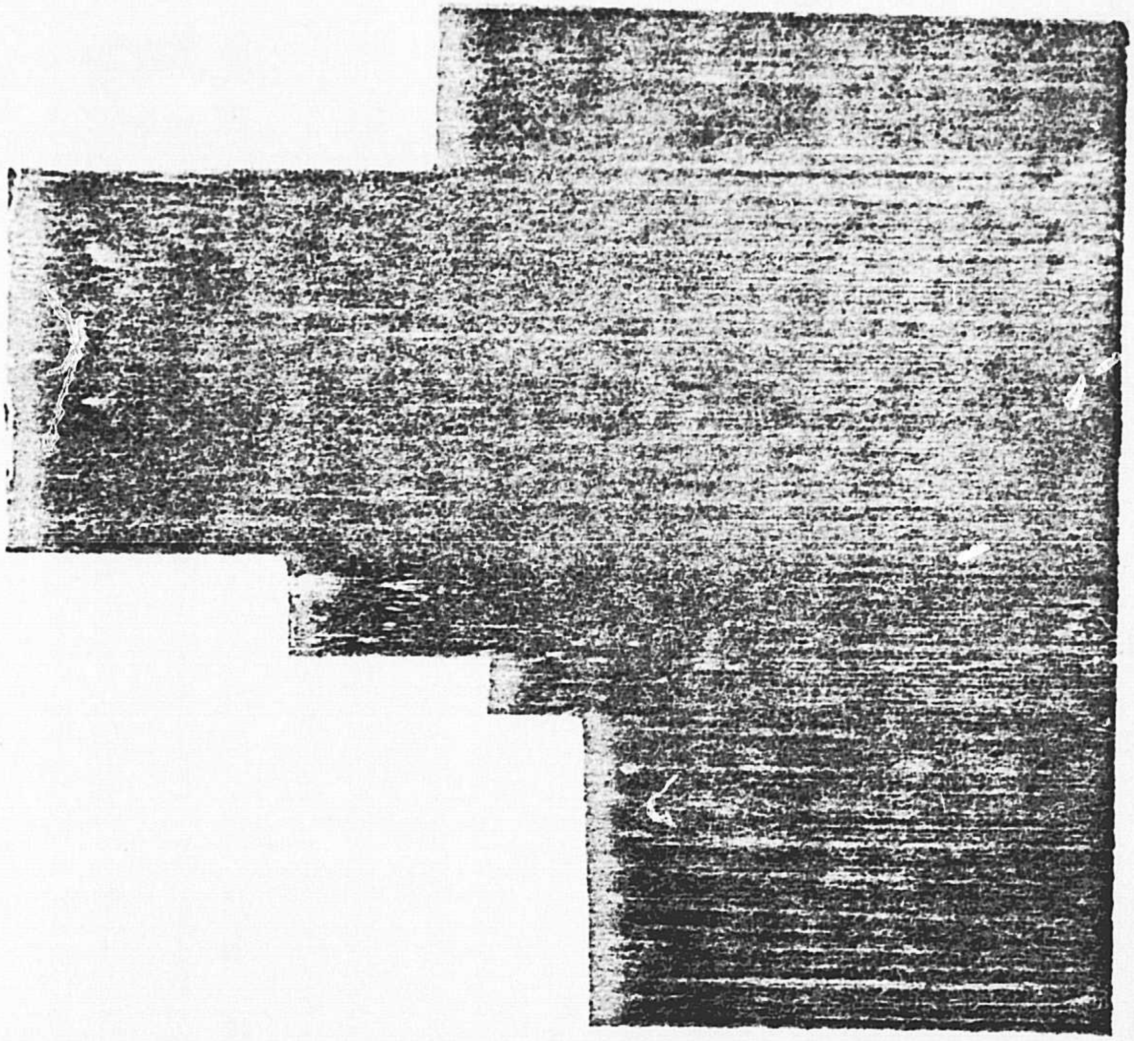

Figure 7. Print of area 3-5-23d at 1524 m agl from black and white film exposed with a red (25) filter taken on August 10, 1973.

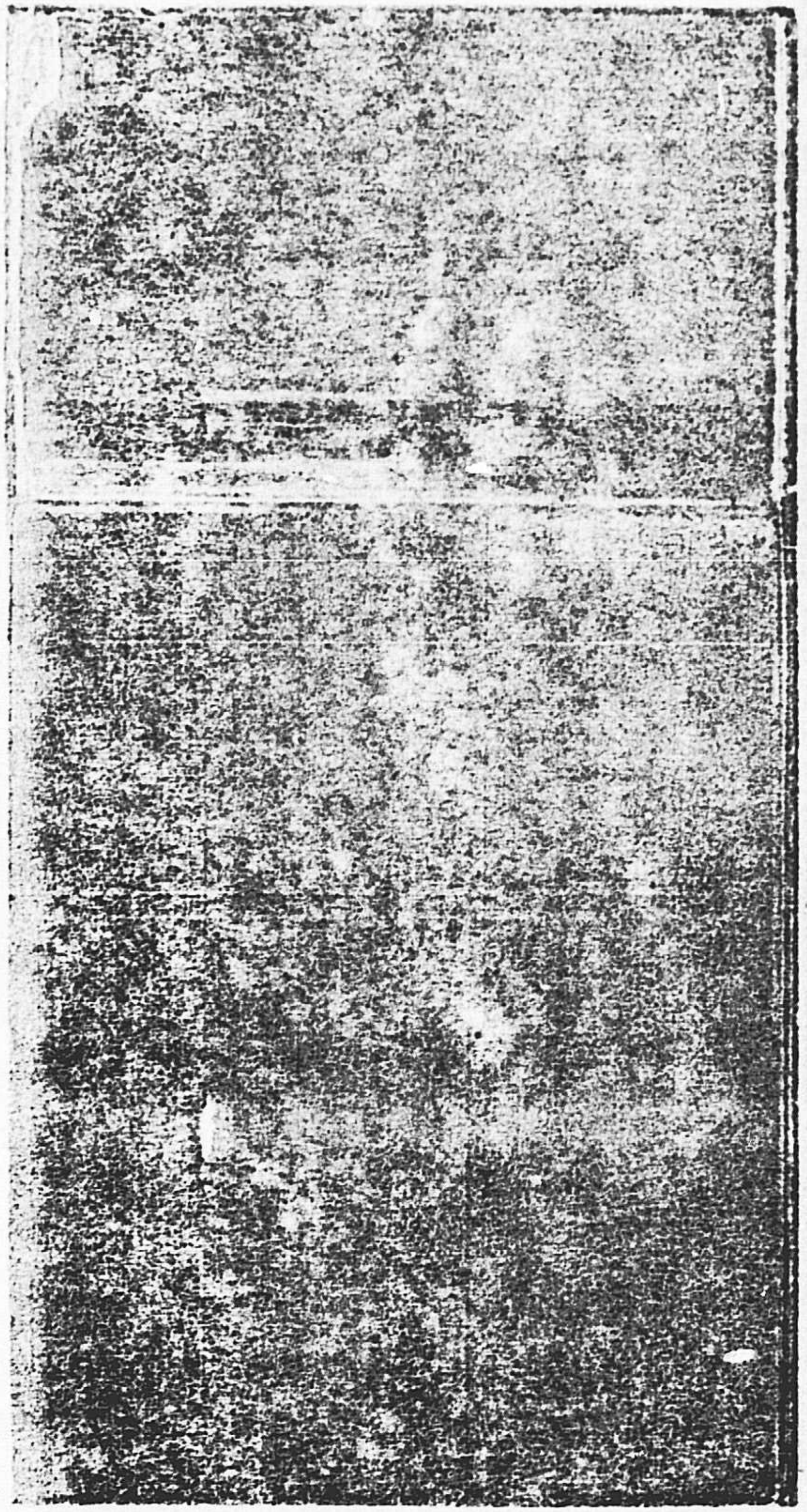

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Figure 8. Print of area 3-5-26a at 1524 m agl from black and white film exposed with a red (25) filter taken on August 10, 1973.

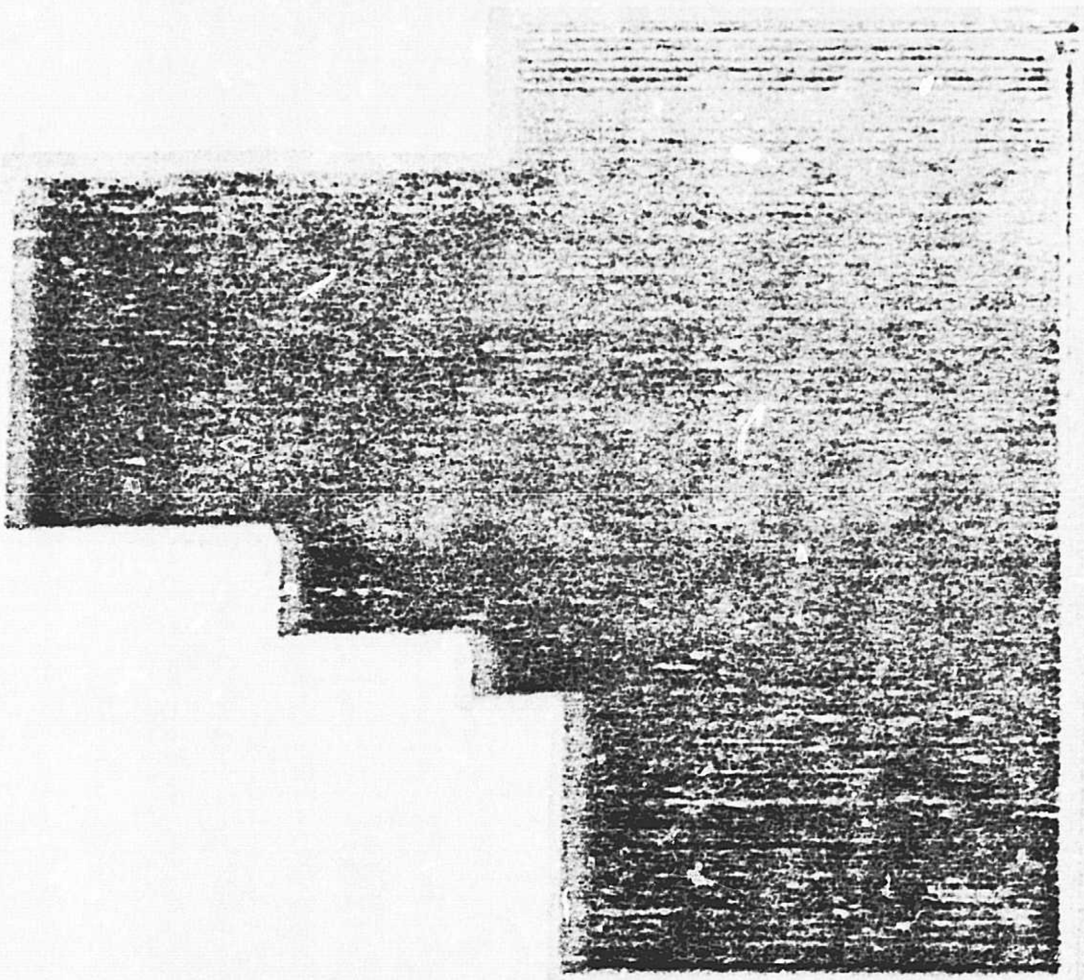

Figure 9. Print of area 3-5-23d at 3048 m agl from black and white film exposed with a red (25) filter taken on June 25, 1974.

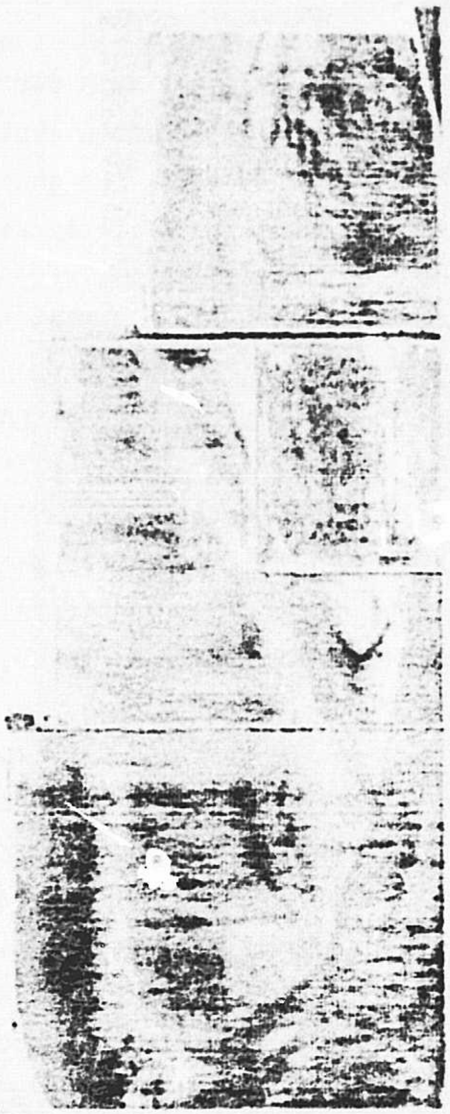

Figure 10. Print of area 2-5-23 at 1524m agl from black and white film exposed with a red (25) filter taken on June 25, 1974.

green (G), and blue (B) filter. The thermal infrared aircraft data was also digitized with SADE by direct analog to digitial transformation.

The water table depth was determined from surface and water table contour maps for each field at locations in a 61m (200 foot) grid interval. Figure 11 is a map of surface and water table depth contours for area 3-5-11a. Only areas of corn were used in the analysis. The linear correlation of the water table depths for each field with the digital values for each LANDSAT-1 MSS band, aircraft films, and aircraft thermal infrared data are presented in Tables III and IV. Table III shows the results for the 1973 data and Table IV for the 1974 data. From Table III the correlation coefficients for the May and August LANDSAT-1 MSS band 7 were significant for all three fields. For the aircraft data the correlation coefficients for color film (neutral or no filter) and black and white film exposed with a red (25) filter were significant for all three fields. From Table IV, the correlation coefficients for thermal infrared taken during the day were significant (0.01 level) for area 3-5-23d for both altitudes.

Various ratios were applied to the variables in Tables III and IV in an attempt to optimize the linear correlation results. The results of the application of the ratios for each area are presented in Tables V and VI. The correlation coefficients for several of the ratios were increased, but no consistent results are apparent.

Multiple linear correlation and regression were applied to each field using the following combinations of independent variables: 1) May and August LANDSAT-1 MSS bands, 2) May and August LANDSAT-1 MSS bands and aircraft thermal infrared (day and night), 3) aircraft films, and 4) aircraft films and aircraft thermal infrared. The multiple correlation coefficient measures the combined relation of the independent variables to the dependent variable. The analysis procedure used for computation of the multiple correlation coefficients and the multiple regression equations selects the independent variable having the highest linear correlation coefficient and adds independent variables in the order providing the highest multiple correlation coefficient. Results for the May and August LANDSAT-1 MSS bands for area 3-5-11a

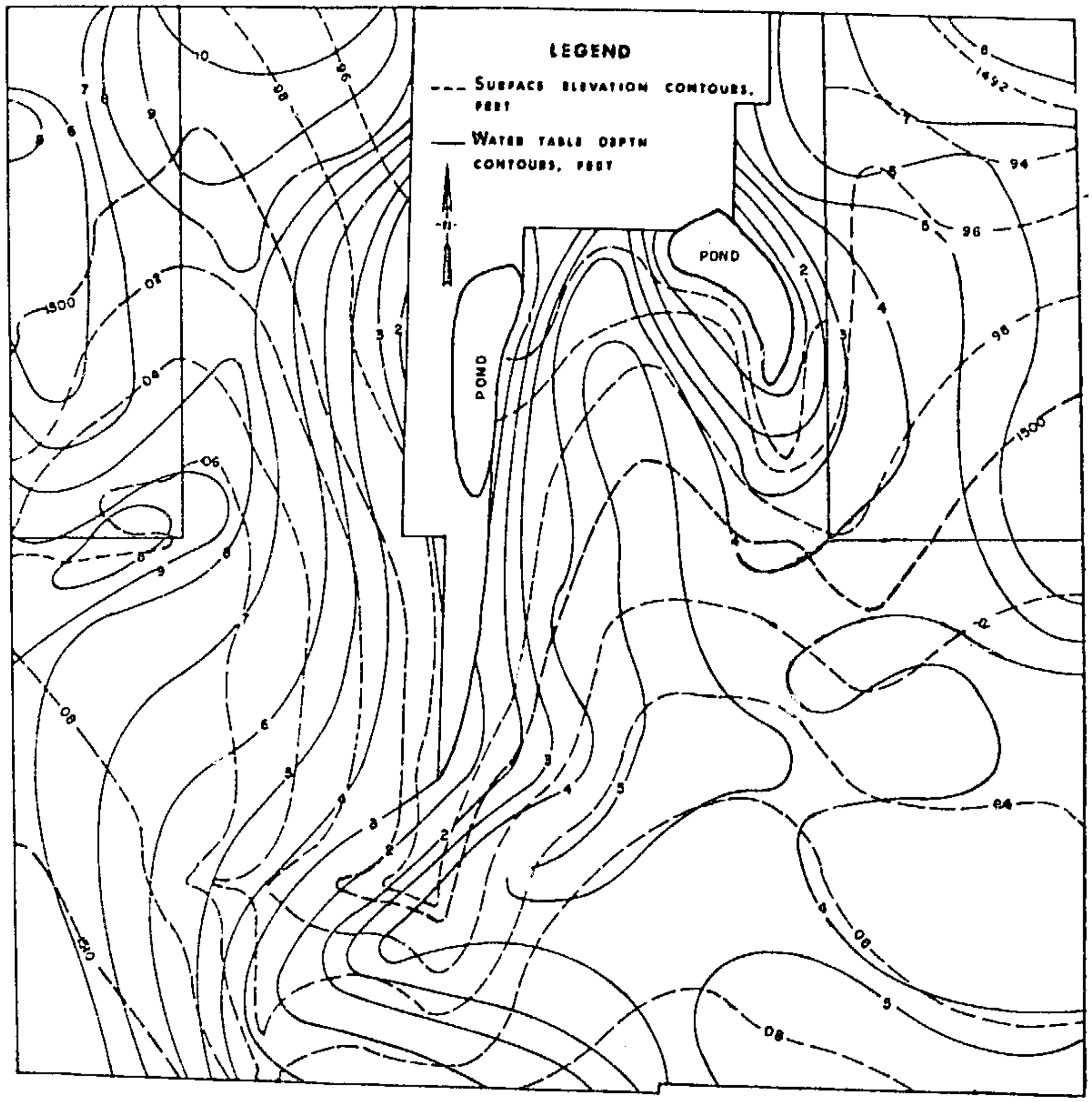

Figure 11. Surface el. ation and water table contours in feet for area 3-5-11a. Approximate scale 1:5,280.

TABLE III CORRELATION COEFFICIENTS FOR DIGITIZED LANDSAT-1 AND AIRCRAFT IMAGERY VERSUS WATER TABLE DEPTH FOR THREE FIELDS IN THE KANSAS/BOSTWICK IRRIGATION DISTRICT FOR 1973 DATA.

VARIABLES	Water Table Depth		
	3-5-11a 118 d.f.	3-5-23d 95 d.f.	3-5-26a 70 d.f.
May 1973 LANDSAT-1 Data			
MSS-4	0.183**	0.011	-0.231
MSS-5	0.243**	-0.226*	-0.270*
MSS-6	0.366**	0.387**	0.194
MSS-7	0.593**	0.277**	-0.304**
August 1973 LANDSAT-1 Data			
MSS-4	0.021	-0.004	-0.343**
MSS-5	0.066	-0.302**	0.089
MSS-6	0.143	-0.155	-0.442
MSS-7	0.312**	0.243*	-0.564**
August 1973 Aircraft Data			
Color IR Film			
Neutral	0.248**	0.018	0.341**
Red	0.265**	0.104	0.145
Green	0.101	0.281**	0.459**
Blue	-0.015	0.336**	0.045
Color Film			
Neutral	0.184*	0.274**	0.574**
Red	0.017	0.216*	0.450**
Green	0.108	0.265**	0.542**
Blue	0.041	0.446**	0.300*
Black & White (25) film	-0.304*	0.280**	-0.381**
Black & White IR film	-0.162*	0.065	0.364**
Thermal IR (day)	-0.034	0.028	-0.534**
Thermal IR (night)	-0.084	-0.007	0.321**

** Significantly different from zero at the one percent level.
* Significantly different from zero at the five percent level.

TABLE IV CORRELATION COEFFICIENTS FOR DIGITIZED AIRCRAFT DATA (JUNE 25 AND 26, 1974) VERSUS WATER TABLE DEPTH FOR AREA 3-5-23d (1524 M AND 3048 M AGL) AND AREA 2-5-23.

VARIABLES	Water Table Depth		
	3-5-23d 1524m AGL 91 d.f.	3-5-23d 3048m AGL 91 d.f.	2-5-23 3048m AGL 78 d.f.
Color IR Film			
Neutral	0.111	0.067	0.023
Red	0.295**	0.195	-0.133
Green	0.023	-0.051	-0.065
Blue	0.201	0.046	-0.082
Color Film			
Neutral	0.040	-0.068	-0.122
Red	0.061	-0.243*	-0.254*
Green	0.257*	-0.215*	-0.159
Blue	0.187	-0.369**	-0.188
Black & White (25) film	0.397**	-0.153	0.130
Black & White IR film	-0.187	-0.387**	0.036
Thermal IR (day)	0.328**	0.406**	-0.099
Thermal IR (night)	0.064	0.030	0.064

** Significantly different from zero at the one percent level.
* Significantly different from zero at the five percent level.

TABLE V. CORRELATION COEFFICIENTS FOR RATIOS OF DIGITIZED LANDSAT-1 AND AIRCRAFT IMAGERY VERSUS WATER TABLE DEPTH FOR THREE FIELDS IN THE KANSAS/BOSTWICK IRRIGATION DISTRICT FOR 1973 DATA.

Ratios	3-5-11a 117 d.f.	3-5-23d 95 d.f.	3-5-26a 70 d.f.
May MSS 4/MSS 5	-0.180*	0.431**	0.188
May MSS 5/MSS 6	-0.016	-0.435**	-0.592**
May MSS 6/MSS 7	-0.224*	0.092	0.734**
Aug MSS 4/MSS 5	-0.059	0.413**	-0.307*
Aug MSS 5/MSS 6	0.043	-0.136	0.374**
Aug MSS 6/MSS 7	-0.205*	-0.378**	0.360**
Aug MSS 4/Thermal IR (Day)	0.037	-0.016	-0.074
Aug MSS 5/Thermal IR (Day)	0.055	-0.285**	0.257*
Aug MSS 6/Thermal IR (Day)	0.128	-0.143	-0.320**
Aug MSS 7/Thermal IR (Day)	0.284**	0.240*	-0.485**
May MSS (4+5+6+7)/Thermal IR (Day)	0.375**	-0.028	-0.147
Aug MSS (4+5+6+7)/Thermal IR (Day)	0.198*	-0.017	-0.447**
May MSS (4+5+6+7)/Thermal IR (Ngt)	0.333**	-0.019	-0.341**
Aug MSS (4+5+6+7)/Thermal IR (Ngt)	0.253**	0.005	-0.477**
CIR N/CIR (R+G+B)	0.382**	-0.199	0.135
CIR R/CIR G	0.383**	-0.123	-0.337**
CIR G/CIR B	0.328**	-0.054	0.430**
CIR N/Thermal IR (Day)	0.234*	0.013	0.440**
Color N/Color (R+G+B)	0.374**	0.019	0.297*
Color R/Color G	-0.230*	-0.048	-0.114
Color G/Color B	0.139	-0.188	0.265*
Color N/Thermal IR (Day)	0.159	0.250*	0.662**
BW (25)/BW IR	-0.110	0.115	-0.412**
BW (25)/Thermal IR (Day)	-0.309**	0.288**	-0.263*
BW IR/Thermal IR (Day)	-0.164	0.057	0.439**
Thermal IR (Day)-Thermal IR (Ngt)	0.033	0.021	-0.575**

* Significantly different from zero at the five percent level.
** Significantly different from zero at the one percent level.

TABLE VI. CORRELATION COEFFICIENTS FOR RATIOS OF DIGITIZED AIRCRAFT DATA (JUNE 25 AND 26, 1974) VERSUS WATER TABLE DEPTH FOR AREA 3-5-23d (1524 M AGL AND 3048 M AGL) AND AREA 2-5-23 (3048 M AGL).

Ratios	3-5-23d 1524 magl 91 d.f.	3-5-23d 3048 magl 91 d.f.	2-5-23 3048 magl 78 d.f.
CIR N/Thermal IR (Day)	-0.225*	-0.259*	0.165
Color N/Thermal IR (Day)	-0.238*	-0.282**	0.086
BW (25)/Thermal IR (Day)	0.055	-0.395**	0.245*
BWIR/Thermal IR (Day)	-0.259*	-0.495**	0.143
Thermal IR (Day)-Thermal IR (Night)	0.304**	0.349**	-0.115
CIR N/CIR (R+G+B)	-0.136	0.055	0.202
CIR R/CIR G	0.277	0.170	0.021
CIR G/CIR B	-0.182	-0.144	0.042
Color N/Color (R+G+B)	-0.236*	0.436**	0.055
Color R/Color G	-0.182	-0.157	-0.223*
Color G/Color B	0.183	0.465**	-0.010
BW (25)/BW IR	0.347**	0.056	0.052
Thermal IR (Day)/Thermal IR (Night)	0.294**	0.365**	-0.103

* Significantly different from zero at the five percent level.
** Significantly different from zero at the one percent level.

in Table VII are presented in analysis of variance form with F-tests used to test for significance. The independent variables are listed in the order of selection. The F-tests indicate the reductions in the sum of squares due to error by including the first two variables one at a time were significant. The regression equation using the first two independent variables is:

$$WTD = 0.159 \text{ (May MSS 7)} + 0.022 \text{ (August MSS 7)} - 6.683$$

where WTD is the dependent variable (water table depth, feet). Substituting digital values obtained with SADE for the independent variables of May LANDSAT-1 MSS band 7 and August LANDSAT-1 MSS band 7 would give the water table depth for the location of each data point. The multiple regression equations for each variable combination for each area are presented in Tables VIII and IX. Each equation was obtained by the same procedure shown in Table VII.

Mode seeking was also applied to the digitized LANDSAT-1 and aircraft data. The mode seeking algorithm classified the data into classes according to the natural clusters or modes and produced a map of the mode of each data point. A mode seeking map was produced for the following variable combinations for each field used in the analysis: 1) LANDSAT-1 (May and August), 2) LANDSAT-1 and aircraft thermal infrared (day and night), 3) aircraft films, and 4) aircraft films and aircraft thermal infrared. A print of the mode seeking output for area 3-5-26a is shown in Figure 12. The numbers represent the mode of each data point as determined by the algorithm. Figure 13 is an example of a computer generated map for the LANDSAT-1 data (May and August) with boundaries drawn between the modes obtained with the mode seeking algorithm for area 3-5-26a. The algorithm uses the mode seeking output to draw the boundaries between each mode or class of data.

To evaluate which variable combination produced the best map in terms of the relationship of the mode outputs to water table depths, a sum of squares of the water table depths for each variable combination was calculated. If the data point clusters or modes are related to water table depths, the total sum of squares of the variance in water table depths will reduce. Therefore, the partitioning of data into classes or modes which has the greatest reduction of total sum of squares was

TABLE VII. MULTIPLE REGRESSION ANALYSIS FOR AREA 3-5-11a USING MAY AND AUGUST LANDSAT-1 MSS BANDS AS INDEPENDENT VARIABLES AND WATER TABLE DEPTH AS THE DEPENDENT VARIABLE.

Independent Variables	Degrees of Freedom	Sum of Squares	Mean Squares	F	Multiple Correlation Coefficient
May MSS 7	1	137.287	137.287	64.153**	0.593
August MSS 7	1	11.150	11.150	5.210*	0.616
May MSS 5	1	2.850	2.850	1.332	
August MSS 5	1	1.109	1.109	0.518	
May MSS 4	1	0.564	0.564	0.264	
August MSS 4	1	0.278	0.278	0.130	
August MSS 6	1	0.007	0.007	0.003	
May MSS 6	1	0.001	0.001	0.001	
Error	111	237.525	2.140		
Total	119	390.771			

* Significant at the five percent level.
** Significant at the one percent level.

TABLE VIII. MULTIPLE REGRESSION EQUATIONS FOR FOUR VARIABLE COMBINATIONS FOR THE THREE FIELDS USED FOR THE 1973 LANDSAT-1 AND AIRCRAFT DATA.

Area (Observation)	Variable Combination	Multiple Regression Equation
	LANDSAT	WTD = 0.159 (May MSS 7) + 0.022 (Aug MSS 7) - 6.683
3-5-11a (119 Obser.)	LANDSAT & Aircraft Thermal	WTD = 0.159 (May MSS 7) + 0.022 (Aug MSS 7) - 6.683
	Aircraft Films	WTD = -0.009 (BW (25)) - 0.172 (clr R) + 0.111 (clr N) + 0.086 (CIR R) - 0.137 (CIR B) + 0.090 (clr B) +5.162
	Aircraft Films & Thermal	WTD = -0.009 (BW (25)) - 0.172 (clr R) + 0.111 (clr N) +0.086 (CIR R) - 0.137 (CIR B) + 0.090 (clr B) + 5.162
3-5-26a (72 Obser.)	LANDSAT	WTD = -0.014 (Aug MSS 7) - 0.013 (Aug MSS 4) - 0.094 (May MSS 7) + 0.101 (May MSS 6) + 6.271
	LANDSAT & Aircraft Thermal	WTD = -0.012 (Aug MSS 7) - 0.017 (Aug MSS 4) - 0.02 (Thermal IR (Day)) + 0.011 (Thermal IR (Ngt)) + + 0.082 (May MSS 6) - 0.073 (May MSS 7) + 8.287
	Aircraft Films	WTD = 0.035 (clr N) + 0.009 (BWIR) - 1.773
	Aircraft Films & Thermal	WTD = 0.02 (clr N) - 0.044 (Thermal IR (Day)) + 0.006 (BWIR) + 0.008 (Thermal IR (Ngt)) + 0.012 (CIR G) - 0.007 (CIR R) + 6.331

TABLE V. . (Continued)

Area (Observation)	Variable Combination	Multiple Regression Equation
3-5-23d (97 Obser.)	LANDSAT	WTD = 0.166 (May MSS 6) - 0.033 (May MSS 5) - 0.129 (Aug MSS 5) + 0.05 (Aug MSS 4) + 2.891
	LANDSAT & Aircraft Thermal	WTD = 0.166 (May MSS 6) - 0.033 (May MSS 5) - 0.129 (Aug MSS 5) + 0.05 (Aug MSS 4) + 2.891
	Aircraft Films	WTD = 0.013 (clr B) + 0.03 (BW (25)) + 0.025 (clr N) + 0.021 (clr G) - 6.673
	Aircraft Films & Thermal	WTD = 0.03 (clr B) - 0.031 (BW (25)) + 0.026 (Thermal (Ngt)) - 3.115

TABLE IX. MULTIPLE REGRESSION EQUATIONS FOR TWO VARIABLE COMBINATIONS FOR THE TWO FIELDS USED FOR THE 1974 AIRCRAFT DATA.

Area	Variable Combination	Multiple Regression Equation
3-5-23d (1524 m agl) 93 Obser.	Aircraft Films	WTD = 0.014 (BW(25)) + 0.041 (clr G) - 3.626
	Aircraft Films & Thermal	WTD = 0.014 (BW (25)) + 0.041 (clr G) - 3.626
3-5-23d (3048 m agl) 93 Obser.	Aircraft Films	WTD = 0.001 (BWIR) - 0.037 (clr B) + 0.047 (CIR R) + 4.123
	Aircraft Films & Thermal	WTD = 0.050 (thermal IR((day)) - 0.010 (BW (25)) + 0.038 (CIR G) - 0.035 (clr R) - 0.501
2-5-23 (3048 m agl) 80 Obser.	Aircraft Films	WTD = -0.034 (clr R) + 0.018 (CIR G) - 0.060 (clr G) + 0.019 (CIR N) + 0.031 (clr N) + 4.967
	Aircraft Films & Thermal	WTD = -0.028 (clr R) + 0.03 (CIR G) - 0.014 (thermal IR (day)) + 0.009 (BW(25)) + 0.022 (CIR N) - 0.037 (clr G) + 3.872

1	1	1	2	2	2	2	2	5	3	3
1	4	4	5	5	5	5	5	5	5	3
1	4	5	6	6	5	5	5	5	3	3
4	4	5	6	6	5	5	6	6	8	3
7	3	6	6	6	6	5	6	6	6	8
7	9	10	10	6	6	6	6	6	6	8
7	9	9	10	10	6	6	6	6	6	8
7	9	9	10	10	6	6	6	6	6	8
9	9	9	10	10	6	6	6	6	6	8
9	9	9	10	10	10	6	6	6	6	8
11	9	9	10	10	10	6	6	6	6	8
11	9	9	10	10	10	10	6	6	6	3
11	12	12	10	10	10	10	10	10	3	3
12	12	8	10	6	6	6	6	6	13	3
12	12	8	10	6	6	6	6	6	13	13
12	12	10	10	10	6	6	10	6	6	6
12	14	10	10	10	10	10	10	10	10	10
12	14	14	14	10	10	10	10	10	3	3
12	17	14	14	14	14	14	14	17	9	9
15	15	16	16	14	14	14	14	17	17	17
15	15	18	18	16	16	16	16	16	17	15
15	15	15	18	18	18	18	15	15	16	15

Figure 12. Mode seeking output using the LANDSAT-1 variable combination (May and August) for area 3-5-26a.

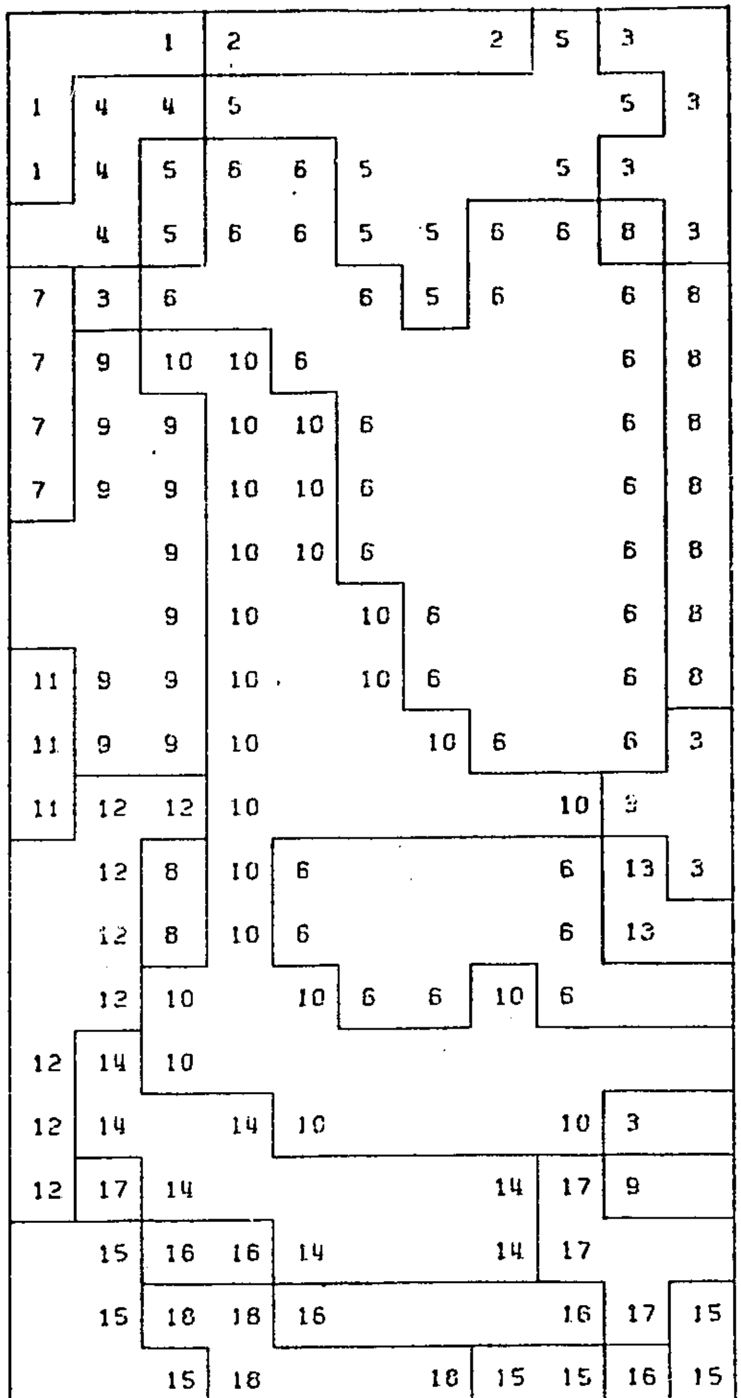

Figure 13. Computer generated map for the LANDSAT-1 data (May and August) of boundaries between modes from mode seeking algorithm for area 3-5-26a.

assumed to be the best map output. The results are presented in Table X. For the 1973 data, the LANDSAT variable combination gave the lowest total sum of squares. For the aircraft data for both years, the difference in the total sum of squares for the two variable combinations does not indicate a definite trend.

Another method of evaluating the mode seeking maps for the variable combinations involved the use of multiple regression. Multiple regression equations were developed for each variable combination for each area using three sets of data points selected by the following three methods: 1) around the perimeter of the field, 2) a grid within the field, and 3) a method utilizing the mode seeking map whereby the number of data points selected in each mode was proportional to the total modal distribution of all of the data points for each field. The procedure therefore resulted in the generation of 36 multiple regression equations for the 1973 data and 18 equations for the 1974 data. The digital data for all of the data points available for each field was then substituted into the multiple regression equations to obtain predicted water table depths for each data point location. The sum of squares was used to evaluate the predicted water table depths.

For the 1973 data the first ten variable combinations are listed in the order of increasing sums of squares in Tables XI, XII, and XIII. For the 1974 data, the 18 variable combinations are listed in the order of increasing sums of squares in Tables XIV, XV, and XVI. The results in Tables XI, XII, and XIII indicate that LANDSAT-1 data may provide a good indication of water table depth. The use of the mode seeking maps as an aid in the selection of data point locations also appears feasible. The results in Tables XIV, XV and XVI for the aircraft data only are not as conclusive as no definite trends are apparent.

Mode seeking combined with K-class classification was also applied to the digitized film data from 1973 for area 3-5-11a. This area was selected because of the range of water table depths in the field (0.61m - 3.05m). The mode seeking algorithm sorts the data values and assigns a mode to each data point. The K-class classifier then uses the mode seeking output as training data for classification of each data point. Twenty features

TABLE X. TOTAL OF THE SUM OF SQUARES FOR EACH MODE FOR EACH VARIABLE COMBINATION FOR EACH FIELD.

Variable Combinations	Sum of Squares					
	1973			1974		
	3-5-11a 1524 m	3-5-23d 1524 m	3-5-26a 1524 m	3-5-23d 1524 m	3-5-23d 3048 m	2-5-23 3048 m
LANDSAT	227.8	66.9	7.1	----	----	----
LANDSAT & Aircraft Thermal	289.3	76.8	7.2	----	----	----
Aircraft Films	310.3	75.5	13.0	68.2	56.3	46.2
Aircraft Films & Aircraft Thermal	304.9	80.8	10.0	69.2	46.3	47.4

TABLE XI. MULTIPLE REGRESSION ANALYSIS OF FOUR VARIABLE COMBINATIONS OF LANDSAT, AIRCRAFT FILMS, AND AIRCRAFT THERMAL DATA FOR THREE METHODS OF OBSERVATION SELECTION AND THREE SETS OF OBSERVATION NUMBERS FOR AREA 3-5-11a. TEN OF THE 36 VARIABLE COMBINATIONS ARE LISTED IN THE ORDER OF INCREASING SUMS OF SQUARES.

Variable Combinations	Method of Observation Selection	Number of Observations	Sums of Squares
LANDSAT and Aircraft Thermal	mode	39	256.5
LANDSAT	grid	20	257.3
LANDSAT and Aircraft Thermal	grid	20	257.3
LANDSAT	mode	10	257.8
LANDSAT and Aircraft Thermal	mode	20	258.0
LANDSAT	grid	39	258.6
LANDSAT	mode	39	262.4
LANDSAT and Aircraft Thermal	mode	10	282.0
LANDSAT and Aircraft Thermal	grid	39	282.8
Aircraft Films	mode	39	311.3

TABLE XII. MULTIPLE REGRESSION ANALYSIS OF FOUR VARIABLE COMBINATIONS OF LANDSAT, AIRCRAFT FILMS, AND AIRCRAFT THERMAL DATA FOR THREE METHODS OF OBSERVATION SELECTION AND THREE SETS OF OBSERVATION NUMBERS FOR AREA 3-5-23d. TEN OF THE 36 VARIABLE COMBINATIONS ARE LISTED IN THE ORDER OF INCREASING SUMS OF SQUARES.

Variable Combinations	Method of Observation Selection	Number of Observations	Sums of Squares
LANDSAT and Aircraft Thermal	mode	42	84.4
LANDSAT	mode	21	84.9
Aircraft Films	grid	42	90.9
Aircraft Films and Aircraft Thermal	grid	42	90.9
LANDSAT	grid	42	91.9
LANDSAT and Aircraft Thermal	grid	42	91.9
LANDSAT	mode	42	95.8
Aircraft Films and Aircraft Thermal	mode	21	101.2
Aircraft Films and Aircraft Thermal	mode	11	104.4
Aircraft Films	mode	42	110.7

TABLE XIII. MULTIPLE REGRESSION ANALYSIS OF FOUR VARIABLE COMBINATIONS OF LANDSAT, AIRCRAFT FILMS, AND AIRCRAFT THERMAL DATA FOR THREE METHODS OF OBSERVATION SELECTION AND THREE SETS OF OBSERVATION NUMBERS FOR AREA 3-5-26a. TEN OF THE 36 VARIABLE COMBINATIONS ARE LISTED IN THE ORDER OF INCREASING SUMS OF SQUARES.

Variable Combinations	Method of Observation Selection	Number of Observations	Sums of Squares
LANDSAT (May & August)	grid	36	6.99
LANDSAT	mode	36	7.02
LANDSAT	perimeter	36	7.32
LANDSAT	mode	18	7.82
LANDSAT & Aircraft Thermal	mode	36	7.85
LANDSAT	grid	18	9.20
LANDSAT & Aircraft Thermal	perimeter	36	9.21
LANDSAT & Aircraft Thermal	mode	18	10.32
Aircraft Films & Aircraft Thermal	perimeter	36	11.86
LANDSAT	grid	9	13.06

TABLE XIV. MULTIPLE REGRESSION ANALYSIS OF TWO VARIABLE COMBINATIONS OF AIRCRAFT FILMS AND AIRCRAFT THERMAL DATA FOR THREE METHODS OF OBSERVATION SELECTION AND THREE SETS OF OBSERVATION NUMBERS FOR AREA 3-5-23d FOR 1524 M AGL (JUNE 25, 1974). THE 18 VARIABLE COMBINATIONS ARE LISTED IN THE ORDER OF INCREASING SUMS OF SQUARES.

Variable Combinations	Method of Observation Selection	Number of Observations	Sum of Squares
Aircraft Films	Mode	42	76.1
Aircraft Films & Aircraft Thermal	Mode	42	76.8
Aircraft Films	Perimeter	42	84.3
Aircraft Films & Aircraft Thermal	Perimeter	42	84.3
Aircraft Films	Perimeter	21	87.4
Aircraft Films	Grid	42	87.9
Aircraft Films & Aircraft Thermal	Grid	42	87.9
Aircraft Films	Grid	11	94.3
Aircraft Films & Aircraft Thermal	Grid	11	102.5
Aircraft Films	Mode	21	103.8
Aircraft Films & Aircraft Thermal	Perimeter	11	109.4
Aircraft Films	Grid	21	121.7
Aircraft Films & Aircraft Thermal	Perimeter	21	129.3
Aircraft Films & Aircraft Thermal	Mode	11	130.9
Aircraft Films	Mode	11	136.4
Aircraft Films & Aircraft Thermal	Mode	21	146.4
Aircraft Films & Aircraft Thermal	Grid	21	157.2
Aircraft Films	Perimeter	11	389.1

TABLE XV. MUTLIPLE REGRESSION ANALYSIS OF TWO VARIABLE COMBINATIONS OF AIRCRAFT FILMS AND AIRCRAFT THERMAL DATA FOR THREE METHODS OF OBSERVATION SELECTION AND THREE SETS OF OBSERVATION NUMBERS FOR AREA 3-5-23d FOR 3048 M AGL (JUNE 25, 1974). THE 18 VARIABLE COMBINATIONS ARE LISTED IN THE ORDER OF INCREASING SUMS OF SQUARES.

Variable Combinations	Method of Observation Selection	Number of Observations	Sum of Squares
Aircraft Films & Aircraft Thermal (Day & Night)	Grid	42	61.7
Aircraft Films & Aircraft Thermal	Mode	42	68.3
Aircraft Films	Grid	42	74.1
Aircraft Films	Mode	42	76.4
Aircraft Films	Perimeter	42	80.1
Aircraft Films & Aircraft Thermal	Perimeter	42	81.9
Aircraft Films & Aircraft Thermal	Mode	11	83.0
Aircraft Films & Aircraft Thermal	Mode	21	89.5
Aircraft Films & Aircraft Thermal	Grid	21	96.0
Aircraft Films	Mode	11	111.3
Aircraft Films	Mode	21	116.6
Aircraft Films	Grid	21	119.4
Aircraft Films	Grid	11	121.3
Aircraft Films & Aircraft Thermal	Grid	11	121.3
Aircraft Films	Perimeter	21	126.4
Aircraft Films	Perimeter	11	181.7
Aircraft Films & Aircraft Thermal	Perimeter	21	1759.7
Aircraft Films & Aircraft Thermal	Perimeter	11	15014.9

TABLE XVI. MULTIPLE REGRESSION ANALYSIS OF TWO VARIABLE COMBINATIONS OF AIRCRAFT FILMS AND AIRCRAFT THERMAL DATA FOR THREE METHODS OF OBSERVATIONS SELECTION AND THREE SETS OF OBSERVATION NUMBERS FOR AREA 2-5-23 FOR 3048 M AGL (JUNE 25, 1974). THE 18 VARIABLE COMBINATIONS ARE LISTED IN THE ORDER OF INCREASING SUMS OF SQUARES.

Variable Combinations	Method of Observation Selection	Number of Observations	Sum of Squares
Aircraft Films	Grid	46	45.3
Aircraft Films & Aircraft Thermal	Grid	46	45.3
Aircraft Films	Mode	46	47.1
Aircraft Films & Aircraft Thermal	Mode	46	47.5
Aircraft Films	Mode	23	51.4
Aircraft Films	Perimeter	46	52.2
Aircraft Films & Aircraft Thermal	Perimeter	46	52.2
Aircraft Films	Grid	23	54.8
Aircraft Films	Mode	12	59.8
Aircraft Films	Perimeter	23	60.6
Aircraft Films & Aircraft Thermal	Perimeter	23	60.6
Aircraft Films & Aircraft Thermal	Mode	23	63.4
Aircraft Films	Grid	12	67.0
Aircraft Films & Aircraft Thermal	Perimeter	12	73.0
Aircraft Films & Aircraft Thermal	Grid	23	76.9
Aircraft Films & Aircraft Thermal	Grid	12	95.3
Aircraft Films & Aircraft Thermal	Mode	12	104.8
Aircraft Films	Perimeter	12	106.3

were used in the analysis and consisted of the following: LANDSAT-1 MSS bands 4, 5, 6, and 7 for May and August 1973; aircraft films (color infrared and color-digitized with no filter (neutral), red, green, and blue filters); black and white film exposed with a red filter; black and white infrared film; and aircraft thermal infrared (day and night). The analysis procedure determined that 18 modes were present and classified the data into 14 classes. Table XVII shows the result after combining the 14 classes into two classes consisting of water table depths of less than 1.83 meters (6 feet) and greater than 1.83 meters. Ninety sampling points (76 percent) out of the 119 total data points were correctly classified into the appropriate depth class. Difficulty in registering the data points for each feature and field edge effects may have contributed to the error in classification of the water table depths as 19 of the 29 data points misclassified were located along the field boundaries.

SUMMARY

Results of this study have shown that both LANDSAT-1 and aircraft remote-sensing data correlated significantly with water table depth for observation wells throughout the Kansas/Bostwick Irrigation District and for specific corn fields selected for analysis. LANDSAT-1 MSS band 6 for May 1973 and MSS band 7 for August 1973 correlated significantly (0.01 level) with water table depth for 144 observation wells. A map of water table depths of less than 1.83 m (6 feet) was generated from the regression equation developed from the August 1973 LANDSAT-1 MSS band 7. The map did not compare favorably with a map of seeped lands showing water tables of less than 1.22 m (4 feet). The LANDSAT-1 map should be evaluated in the field to provide an indication as to whether it is feasible to attempt to refine the technique.

Analysis of single fields selected within the irrigation district showed similar results for LANDSAT-1 data. The May MSS band 7 and August MSS band 7 correlated significantly with water table depth for three fields. With the significant results obtained from LANDSAT-1, 9 x 9 inch transparencies, it is believed that computer compatible tapes (CCT's) may provide even better results. Each MSS band is registered on the CCT's and therefore would provide the accurate registration among the various bands for a

TABLE XVII. TWO-CLASS MODE SEEKING AND K-CLASS CLASSIFICATION ANALYSIS FOR AREA 3-5-11a USING 1973 DATA.

Water Table Depth Class	Water Table Depth Range (Meters)	Letter Designation for Each Data Point Classified										Correct Classifications
		a	b	a	a	a	b	a	a	a	a	8
		a	a	a	a	a	a	a	a	a	b	9
	0.61	a	a	a	b	a	a	a	b	a	a	8
a	thru	a	b	a	a	a	a	a	a	a	a	9
	1.77	a	a	a	a	a	a	a	b	a	b	8
		a	a	a	a	a	a	a	a	a	a	10
		b	a	a	b	a	b	b	a	b	a	5
		a	b	b								1
		b	a	b	b	a	b	b	b	b	a	7
	1.83	b	b	b	b	a	b	a	b	b	b	8
	thru	b	b	a	b	a	a	b	b	b	a	6
b	3.05	b	a	b	b	a	b	b	b	b	b	8
		b	a	b	a	b	a					3
	TOTAL CORRECT CLASSIFICATIONS											90

multispectral analyses. In addition, the radiometric information is probably better from the tapes than from the analog transparencies.

For the aircraft data for specific fields the results were not consistent. Significant correlations were obtained for the black and white film exposed with a red filter versus water table depth for four of the fields studied. Color film digitized with a green filter and a red filter also provided significant results for four of the fields.

The application of mode seeking to the LANDSAT-1 and aircraft data also showed the potential of LANDSAT-1 data for use in developing maps relating to water table depth. The mode seeking algorithm was applied to each of the following variable combinations for each field: 1) LANDSAT-1 (May and August), 2) LANDSAT-1 and aircraft thermal infrared (day and night), 3) aircraft films, and 4) aircraft films and aircraft thermal infrared. The LANDSAT-1 variable combiantion gave the lowest total sum of squares for the three fields studied.

A multiple regression analysis was also used whereby the predicted water table depth was compared with the actual water table depth for the four variable combinations listed in the previous paragraph. The multiple regression equations were developed for each variable combination for each field using three sets of data points selected by three methods. Again using the sum of squares to evaluate the variation between the predicted and actual water table depth, the LANDSAT-1 variable combination provided the least variation and therefore the best prediction of water table depth.

Computer compatible digital tapes are being obtained and similar analysis will be prepared for this data. Field evaluation of the map generated products will be made.